

Associations between novel anthropometric variables and short-term outcomes after acute type A aortic dissection repair

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Research Article

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Abstract

Background: The impact of body mass index—defined obesity on outcomes after acute type A aortic dissection (ATAAD) repair remains controversial. This study aimed to determine the associations between novel anthropometric variables and short-term outcomes in ATAAD patients after aortic repair.

Methods: A retrospective analysis was conducted on 794 ATAAD patients from January 2019 to November 2023. We performed univariate, multivariable, average marginal effect, interaction and mediation effect, and restricted cubic spline analyses to investigate the associations between anthropometric variables and short-term outcomes (including short-term mortality, ischemic stroke and acute kidney injury, (AKI), etc).

Results: Relative fat mass (RFM) was independently associated with postoperative AKI in ATAAD, and each one-unit increase in RFM was associated with a 2.10% (95% CI: 0.0131-0.0288, $P < 0.001$) change in the probability of postoperative AKI for average patient. RFM and cardiopulmonary bypass (CPB) duration had a synergistic effect on AKI (OR: 1.0004, 95%CI: 1.0000-1.0009, $P=0.040$). Neutrophil count partially mediated the RFM-AKI relationship (proportion mediated: 12.5%). Additionally, waist circumference (WC), RFM, waist-to-height ratio (WHtR), and body roundness index (BRI) exhibited nonlinear, U-shaped associations with short-term mortality in ATAAD, with lowest predicted probability at 907 mm for WC, 38.5 for RFM, 0.544 for WHtR, and 4.35 for BRI.

Conclusions: RFM was independently associated with postoperative AKI in ATAAD patients, mediated partially by inflammatory/stress responses and synergized with prolonged CPB duration. Central obesity indicators (WC, RFM, WHtR, BRI) showed U-shaped associations with short-term mortality. RFM should be prioritized for perioperative risk assessment, especially during extended CPB procedures.

Introduction

Acute type A aortic dissection (ATAAD) is a life-threatening cardiovascular emergency that demands urgent surgical intervention [1]. Despite ongoing advances in surgical techniques and postoperative care, the associated morbidity and mortality remain high, and the risk of death can increase by 1%–2% per hour without prompt treatment [2]. Meanwhile, obesity, traditionally viewed as a cardiovascular risk factor, appears to display a paradoxical influence on surgical outcomes, with evidence suggesting that both underweight and morbidly obese individuals demonstrate higher mortality rates, implying a U-shaped relationship between body weight and surgical outcomes [3]. In ATAAD repair, existing studies suggest that body mass index (BMI) is associated with both short- and long-term outcomes [4, 5]. However, inconclusive results were reported recently that “obesity paradox” might not be applied in the setting of acute aortic dissection as no differences were found in survival rate among four BMI-based groups [6]. These conflicting findings highlight the complexity of obesity’s role in surgical outcomes and suggest that factors beyond BMI may influence outcomes in ATAAD patients.

Novel anthropometric variables, such as waist circumference (WC), waist-to-height ratio (WHtR) [7], a body shape index (ABSI) [8], relative fat mass (RFM) [9], body roundness index (BRI) [10], and conicity index (C-Index) [11], have been developed as promising alternative indexes for obesity [12–14], but their impact on short-term outcomes in ATAAD remains insufficiently explored. Therefore, this study aimed to determine the association between anthropometric variables and short-term outcomes in ATAAD after aortic repair.

Methods

Patient collection

This retrospective study was approved by the Ethics Committee of the Second Xiangya Hospital of Central South University (LYF2023113) on 02/08/2023, and the need for written informed consent was waived. Data for this study were accessed for research purposes between 02/08/2023 and 31/07/2024, in accordance with the approved ethical protocol. Between January 2019 to November 2023, a total of 796 patients diagnosed with acute type A aortic dissection who underwent ATAAD repair at the Second Xiangya Hospital of Central South University were enrolled in this study. Two patients were excluded due to CT data missing. Eventually, 794 patients were included in this study.

Anthropometric variables

Nine anthropometric variables were analyzed including height, weight, WC, C-index, ABSI, RFM, WHtR, BRI, and BMI. WC was measured in millimetre (mm) at the point midway between the superior margin of iliac crest and the costal margin (lower rib) using CT data. WHtR was calculated as WC (cm)/height (cm) [7]. BMI was defined as body weight (kg) / height² (m). ABSI was calculated as: WC (m) / [BMI^{2/3} (kg/m²) × height^{1/2} (m)] [8]. RFM was calculated as: 64 - [20 × height(m) / WC(m)] + (12 × sex [0-men, 1-women]) [9]. BRI: 364.2–365.5 × [1 - [WC (m) / 2π]² / (height (m) / 2)²]^{1/2} [10]. C-Index: WC (m) / [0.109 × weight (kg) / height^{1/2} (m)] [11].

Definitions of outcomes

Short-term outcomes assessed during hospitalization included short-term mortality, ischemic stroke, acute kidney injury (AKI), continuous renal replacement therapy (CRRT), cardiac arrest, tracheostomy, and intensive care unit (ICU) duration. Short-term mortality is defined as death of any cause occurring intraoperatively or within 30 days postoperatively. Ischemic stroke is defined as follows: (1) the patient presents with new onset symptoms within 30 days postoperatively; (2) symptoms include focal neurological dysfunctions such as weakness or numbness of one side of the face or limbs, speech disorders, and other comprehensive neurological deficits; (3) the duration of symptoms/signs is not limited when the responsible lesions are confirmed by CT or MRI; otherwise, the duration should be more than 24 hours; (4) non-vascular causes of symptoms/signs are excluded; and (5) postoperative hemorrhagic stroke is also ruled out. AKI is defined according to the 2012 KDIGO clinical practice guidelines [15].

Surgical techniques

The brief surgical techniques involves that a 4-branched graft was utilized to reconstructed aortic arch and a 12 cm stented graft was inserted into the true lumen of the descending aorta. The anastomosis sequence was performed in the following order: proximal ascending aorta, left carotid artery, proximal descending aorta, innominate artery, and left subclavian artery. Moderate or mild hypothermia and bilateral or unilateral cerebral perfusion may vary depending on the different surgeons. Additionally, the perfusion flow during lower body circulatory arrest (LBCA) was different based on the temperature of hypothermic circulatory arrest (8-10ml/kg/min or 0.6-1.2L/m²/min). The other details of surgical techniques have been previously described in a published study [16].

Statistical Analyses

All the statistical analyses were performed in SPSS 27.0 and R studio 4.4.1. All P values were two-tailed, and statistical significance was defined as $P < 0.05$. Multiple imputation was used for missing data when the missing portion was less than 20%. Predictive mean matching was used to impute numeric variables, and logistic regression was used to impute binary variables.

For univariate analysis, Chi-square test, corrected Chi-square test, and Fisher exact test were used to compare categorical variables, while Student t-test and Mann-Whitney U test were respectively used to compare continuous variables of normal and non-normal distribution. For comparison of three groups, Chi-square test, Fisher exact test or Fisher's exact test with Monte Carlo simulation ($B = 10,000$) were initially used to examine the association between categorical variables. Post-hoc pairwise comparisons were conducted with Bonferroni correction. For continuous variables, one-way analysis of variance (ANOVA) was applied for normally distributed data, and the Kruskal-Wallis test was used for non-normally distributed data to assess differences among the three groups. Post-hoc pairwise comparisons were performed using the Tukey Honest Significant Difference test for ANOVA results and the Dunn test with Bonferroni correction for Kruskal-Wallis results. Univariate analyses were performed to evaluating the associations between anthropometric variables and clinical outcomes. All 794 patients were included in the mortality analysis, whereas nine patients were excluded from the analyses of other outcomes due to intraoperative or early postoperative death.

For the risk factor analysis, univariate analyses were conducted to identify potential risk factors, and variables with a $P \text{ value} < 0.05$ were included in the multivariable analysis to determine the independent risk factors. The least absolute shrinkage and selection operator (LASSO) regression was applied to minimize the multicollinearity of anthropometric variables. Multicollinearity was evaluated using the variance inflation factor (VIF).

Average marginal effect (AME) analysis

AME analysis was conducted to evaluate the effect of RFM on the probability of postoperative AKI in the overall cohort, as well as in male and female subgroups, while holding other covariates constant at their mean values.

Mediation analysis for the effect of RFM on AKI: First, we fitted a linear regression model with the mediator (neutrophil count) as the dependent variable and RFM as the independent variable, controlling for key covariates including age and sex. Next, we built a logistic regression model for AKI that included RFM, the mediator (neutrophil count), and covariates including: sex, time from admission to operation, cardiopulmonary bypass (CPB) duration, aorta clamping duration and low body circulatory arrest duration. To estimate the average causal mediation effect, the average direct effect and the proportion mediated we used the 'mediate' function from the mediation package in R. Nonparametric bootstrap simulations (1,000 iterations) were performed to obtain robust 95% confidence intervals and p-values.

Restricted cubic spline (RCS) analyses

RCS analysis (three knots) was conducted to examine the nonlinear associations between anthropometric variables and outcomes, and the covariates included age, sex, platelet count, aortic sinus repair, CPB duration, re-CPB, and previous heart surgery. Among them, platelet count, aortic sinus repair, CPB duration and re-CPB were identified as independent risk factors of short-term mortality in present study, whereas age, sex, and previous heart surgery were included because they are recognized risk factors [17].

Results

Baseline Characteristics and univariate analysis between anthropometric variables and outcomes

Baseline characteristics of all patients are summarized in Table S1. Of the 794 participants, 612 (77.1%) were men, with a mean age of 50.7 ± 11.2 years. Univariate analyses were conducted to evaluate the relationships between anthropometric variables and clinical short-term outcomes, with detailed results presented in Table S2,S3,S4,S5,S6,S7,S8 and S9. The overall short-term mortality is 6.2%, while the incidence of postoperative ischemic stroke and AKI are 6.4% and 38.5%, respectively. Consequently, no significant associations were found between anthropometric variables and short-term mortality, ischemic stroke, CRRT, cardiac arrest or tracheostomy. However, seven anthropometric variables including height, weight, WC, RFM, WHtR, BRI and BMI were associated with AKI, with higher values correlating with an increased incidence of postoperative AKI. Additionally, C-index and ABSI showed a positive association with ICU duration (Fig. 1).

Table S1
Univariate and multivariable logistic regression analyses of short-term mortality

Variables	Overall (n = 794)	Mortality group (n = 49)	Non-mortality group (n = 745)	Univariate P value	OR	95% CI	Multivariate P value	VIF
Male (%)	612 (77.1)	34 (69.4)	578 (77.6)	0.251				
Age, year (SD)	50.65 (11.20)	51.53 (10.12)	50.59 (11.27)	0.570				
Height, cm (SD)	167.18 (7.71)	167.37 (9.16)	167.16 (7.61)	0.858				
Weight, kg (SD)	72.97 (14.19)	73.18 (15.64)	72.96 (14.10)	0.915				
WC, mm (SD)	913.34 (107.65)	908.58 (137.27)	913.65 (105.52)	0.750				
C-index (SD)	1.27 (0.08)	1.26 (0.09)	1.27 (0.08)	0.374				
ABSI (SD)	0.08 (0.00)	0.08 (0.00)	0.08 (0.00)	0.390				
RFM (SD)	38.94 (4.21)	38.44 (5.30)	38.98 (4.13)	0.389				
WHtR (SD)	0.55 (0.06)	0.54 (0.08)	0.55 (0.06)	0.680				
BRI (SD)	4.34 (1.27)	4.32 (1.62)	4.35 (1.24)	0.867				
BMI (SD)	26.00 (4.08)	25.98 (4.48)	26.00 (4.05)	0.979				
Hypertension (%)	582 (73.3)	41 (83.7)	541 (72.6)	0.127				
CAD (%)	42 (5.3)	3 (6.1)	39 (5.2)	1.000				
Previous heart surgery (%)	14 (1.8)	2 (4.1)	12 (1.6)	0.476				
Diabetes mellitus (%)	27 (3.4)	3 (6.1)	24 (3.2)	0.497				
Smoker (%)	315 (39.7)	22 (44.9)	293 (39.3)	0.535				

OR: odds ratio; CI: confidence interval; VIF: variance inflation factor; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO₂: peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.

Variables	Overall (n = 794)	Mortality group (n = 49)	Non-mortality group (n = 745)	Univariate P value	OR	95% CI	Multivariate P value	VIF
SpO ₂ at admission, % (SD)	95.77 (2.72)	95.45 (3.57)	95.79 (2.65)	0.398				
White blood cell count, 10 ⁹ /L (SD)	12.72 (3.76)	13.26 (4.12)	12.68 (3.74)	0.295				
Neutrophil count, 10 ⁹ /L (SD)	10.95 (3.61)	11.46 (3.99)	10.92 (3.59)	0.304				
Lymphocyte count, 10 ⁹ /L (SD)	1.02 (0.47)	1.05 (0.38)	1.02 (0.48)	0.617				
Hematocrit, % (SD)	39.33 (5.28)	39.22 (6.40)	39.34 (5.20)	0.880				
Platelet count, 10 ⁹ /L (SD)	181.37 (71.23)	159.98 (45.01)	182.77 (72.42)	0.030	0.994	0.989-1.000	0.042	1.02
PT, s (SD)	13.87 (2.10)	14.01 (2.70)	13.86 (2.06)	0.636				
INR (SD)	1.10 (0.19)	1.13 (0.25)	1.10 (0.19)	0.246				
APTT, s (SD)	37.05 (7.21)	36.41 (7.79)	37.10 (7.18)	0.522				
Alanine transaminase, U/L (IQR)	21.80 [14.10, 35.38]	28.00 [15.40, 42.20]	21.50 [14.10, 35.00]	0.248				
Aspartate transaminase, U/L (IQR)	23.20 [17.90, 35.55]	31.00 [21.00, 77.90]	23.00 [17.80, 34.10]	0.003			Excluded	
Total bilirubin, µmol/L (SD)	17.07 (13.45)	17.08 (9.60)	17.07 (13.67)	0.997				
Direct bilirubin, µmol/L (SD)	5.91 (3.59)	5.98 (3.42)	5.91 (3.61)	0.897				
Creatinine, µmol/L (SD)	122.39 (121.16)	128.22 (137.64)	122.01 (120.09)	0.728				
Left ventricle diameter, cm (SD)	46.83 (6.00)	48.20 (6.45)	46.74 (5.97)	0.098				

OR: odds ratio; CI: confidence interval; VIF: variance inflation factor; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO₂: peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.

Variables	Overall (n = 794)	Mortality group (n = 49)	Non-mortality group (n = 745)	Univariate P value	OR	95% CI	Multivariate P value	VIF
LVEF, % (SD)	65.03 (7.15)	64.76 (7.37)	65.05 (7.14)	0.782				
Time from onset to admission, h (SD)	13.00 [8.00, 24.00]	12.00 [8.00, 20.00]	13.00 [8.00, 25.00]	0.253				
Time from admission to operation, h (SD)	16.00 [10.00, 28.45]	14.67 [8.00, 24.00]	16.00 [10.00, 28.75]	0.149				
Surgeon (%)				0.255				
1	266 (33.5)	21 (42.9)	245 (32.9)					
2	254 (32.0)	11 (22.4)	243 (32.6)					
3	257 (32.4)	17 (34.7)	240 (32.2)					
4	17 (2.1)	0 (0.0)	17 (2.3)					
Concomitant procedures (%)								
Bentall	53 (6.7)	5 (10.2)	48 (6.4)	0.468				
Aortic sinus repair	409 (51.5)	18 (36.7)	391 (52.5)	0.047	0.414	0.218–0.787	0.007	1.07
CABG	49 (6.2)	7 (14.3)	42 (5.6)	0.033			Excluded	
Cannulation (%)				0.100				
Axillary artery	450 (56.7)	23 (46.9)	427 (57.3)					
Femoral artery	122 (15.4)	13 (26.5)	109 (14.6)					
Axillary and femoral artery	205 (25.8)	11 (22.4)	194 (26.0)					
Others	17 (2.1)	2 (4.1)	15 (2.0)					
Times, min (SD)								
OR: odds ratio; CI: confidence interval; VIF: variance inflation factor; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.								

Variables	Overall (n = 794)	Mortality group (n = 49)	Non-mortality group (n = 745)	Univariate P value	OR	95% CI	Multivariate P value	VIF
CPB	232.41 (97.15)	310.80 (172.05)	227.26 (87.86)	< 0.001	1.006	1.004–1.009	< 0.001	1.05
Aorta clamping	109.45 (55.32)	136.22 (78.15)	107.69 (53.08)	< 0.001			Excluded	
LBCA	21.21 (7.89)	21.12 (9.23)	21.22 (7.80)	0.934				
Re-CPB (%)	127 (16.0)	19 (38.8)	108 (14.5)	< 0.001	3.092	1.600–5.973	< 0.001	1.01
LBCA flow, L/min (SD)	1.36 (0.64)	1.47 (0.63)	1.36 (0.64)	0.244				
Nasopharyngeal temperature, °C (SD)	27.74 (2.04)	27.72 (2.34)	27.74 (2.02)	0.936				
Bladder temperature, °C (SD)	28.56 (2.22)	28.52 (2.60)	28.56 (2.20)	0.913				
OR: odds ratio; CI: confidence interval; VIF: variance inflation factor; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.								

Table S2
Univariate analyses between anthropometric variables and short-term mortality

Variables	Overall (n = 794)	Mortality group (n = 49)	Non-mortality group (n = 745)	P value
Height (cm)	167.18 (7.71)	167.37 (9.16)	167.16 (7.61)	0.858
Weight (kg)	72.97 (14.19)	73.18 (15.64)	72.96 (14.10)	0.915
WC (mm)	913.34 (107.65)	908.58 (137.27)	913.65 (105.52)	0.801
C-index	1.27 (0.08)	1.26 (0.09)	1.27 (0.08)	0.374
ABSI	0.08 (0.00)	0.08 (0.00)	0.08 (0.00)	0.390
RFM	38.94 (4.21)	38.44 (5.30)	38.98 (4.13)	0.492
WHtR	0.55 (0.06)	0.54 (0.08)	0.55 (0.06)	0.743
BRI	4.34 (1.27)	4.32 (1.62)	4.35 (1.24)	0.895
BMI (kg/m ²)	26.00 (4.08)	25.98 (4.48)	26.00 (4.05)	0.979
All data were present as mean (Standard Deviation). OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.				

Table S3
Univariate analyses between anthropometric variables and ischemic stroke

Variables	Overall (n = 785)	Stroke group (n = 50)	Non-stroke group (n = 735)	P value
Height (cm)	167.22 (7.62)	165.38 (7.04)	167.35 (7.65)	0.077
Weight (kg)	73.08 (14.13)	70.13 (13.22)	73.28 (14.18)	0.127
WC (mm)	914.16 (107.09)	895.75 (100.53)	915.42 (107.47)	0.209
C-index	1.27 (0.08)	1.27 (0.07)	1.27 (0.08)	0.499
ABSI	0.08 (0.00)	0.08 (0.01)	0.08 (0.00)	0.282
RFM	38.97 (4.17)	38.68 (3.83)	38.99 (4.19)	0.614
WHtR	0.55 (0.06)	0.54 (0.05)	0.55 (0.06)	0.509
BRI	4.35 (1.26)	4.22 (1.10)	4.36 (1.27)	0.462
BMI (kg/m ²)	26.02 (4.06)	25.49 (3.60)	26.06 (4.09)	0.341
All data were present as mean (Standard Deviation). OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.				

Table S4
Univariate analyses between anthropometric variables and postoperative AKI

Variables	Overall (n = 785)	AKI group (n = 302)	Non-AKI group (n = 483)	P value	OR (95% CI)
Height (cm)	167.22 (7.62)	168.23 (7.61)	166.59 (7.57)	0.003	1.029 (1.009, 1.049)
Weight (kg)	73.08 (14.13)	77.06 (14.38)	70.60 (13.40)	< 0.001	1.034 (1.023, 1.045)
WC (mm)	914.16 (107.09)	944.16 (102.70)	895.41 (105.60)	< 0.001	1.004 (1.003, 1.006)
C-index	1.27 (0.08)	1.28 (0.07)	1.27 (0.08)	0.025	25.636 (3.743, 175.568)
ABSI	0.08 (0.00)	0.08 (0.00)	0.08 (0.01)	0.334	Not significant
RFM	38.97 (4.17)	40.00 (3.70)	38.33 (4.32)	< 0.001	1.109 (1.068, 1.151)
WHtR	0.55 (0.06)	0.56 (0.06)	0.54 (0.06)	< 0.001	774.189 (63.609, 9422.782)
BRI	4.35 (1.26)	4.65 (1.22)	4.17 (1.25)	< 0.001	1.359 (1.207, 1.530)
BMI (kg/m ²)	26.02 (4.06)	27.10 (4.01)	25.35 (3.95)	< 0.001	1.116 (1.075, 1.158)
All data were present as mean (Standard Deviation). AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.					

Table S5
Univariate analyses between anthropometric variables and CRRT

Variables	Overall (n = 785)	CRRT group (n = 73)	Non-CRRT group (n = 712)	P value
Height (cm)	167.22 (7.62)	168.04 (7.31)	167.14 (7.65)	0.335
Weight (kg)	73.08 (14.13)	75.12 (16.48)	72.87 (13.87)	0.265
WC (mm)	914.16 (107.09)	933.61 (125.80)	912.17 (104.88)	0.103
C-index	1.27 (0.08)	1.29 (0.09)	1.27 (0.08)	0.102
ABSI	0.08 (0.00)	0.08 (0.01)	0.08 (0.00)	0.165
RFM	38.97 (4.17)	39.42 (4.69)	38.93 (4.11)	0.333
WHtR	0.55 (0.06)	0.56 (0.07)	0.55 (0.06)	0.202
BRI	4.35 (1.26)	4.55 (1.47)	4.33 (1.24)	0.154
BMI (kg/m ²)	26.02 (4.06)	26.46 (4.91)	25.98 (3.97)	0.421
All data were present as mean (Standard Deviation). CRRT: continuous renal replacement therapy; OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.				

Table S6
Univariate analyses between anthropometric variables and cardiac arrest

Variables	Overall (n = 785)	Cardiac arrest (n = 35)	Non-cardiac arrest group (n = 750)	P value
Height (cm)	167.22 (7.62)	167.83 (6.30)	167.19 (7.68)	0.630
Weight (kg)	73.08 (14.13)	73.80 (16.08)	73.05 (14.05)	0.759
WC (mm)	914.16 (107.09)	923.04 (140.21)	913.75 (105.39)	0.701
C-index	1.27 (0.08)	1.28 (0.09)	1.27 (0.08)	0.635
ABSI	0.08 (0.00)	0.08 (0.01)	0.08 (0.00)	0.550
RFM	38.97 (4.17)	38.91 (5.11)	38.98 (4.12)	0.944
WHtR	0.55 (0.06)	0.55 (0.08)	0.55 (0.06)	0.839
BRI	4.35 (1.26)	4.44 (1.63)	4.35 (1.24)	0.730
BMI (kg/m ²)	26.02 (4.06)	26.05 (4.76)	26.02 (4.03)	0.972
All data were present as mean (Standard Deviation). OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.				

Table S7
Univariate analyses between anthropometric variables and tracheostomy

Variables	Overall (n = 785)	Tracheostomy group (n = 27)	Non-tracheostomy group (n = 758)	P value
Height (cm)	167.22 (7.62)	169.48 (8.09)	167.14 (7.60)	0.117
Weight (kg)	73.08 (14.13)	76.17 (15.08)	72.97 (14.10)	0.249
WC (mm)	914.16 (107.09)	941.13 (96.42)	913.20 (107.38)	0.183
C-index	1.27 (0.08)	1.30 (0.07)	1.27 (0.08)	0.134
ABSI	0.08 (0.00)	0.08 (0.01)	0.08 (0.00)	0.174
RFM	38.97 (4.17)	39.66 (3.78)	38.95 (4.18)	0.382
WHtR	0.55 (0.06)	0.56 (0.05)	0.55 (0.06)	0.433
BRI	4.35 (1.26)	4.52 (1.13)	4.34 (1.27)	0.473
BMI (kg/m ²)	26.02 (4.06)	26.40 (4.19)	26.01 (4.06)	0.914
All data were present as mean (Standard Deviation). OR: odds ratio; CI: confidence interval; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.				

Table S8
Pearson correlation analyses between anthropometric variables and ICU duration

Variables	Pearson correlation (n = 785)	P value
Height	-0.062	0.085
Weight	-0.026	0.473
WC	0.028	0.437
C-index	0.083	0.020
ABSI	0.088	0.014
RFM	0.045	0.210
WHtR	0.052	0.145
BRI	0.055	0.122
BMI	-0.004	0.907
ICU: intensive care unit; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.		

Table S9
P values of univariate analyses between anthropometric variables and outcomes

Variables	Short-term death	Ischemic stroke	AKI	CRRT	Cardiac arrest	Tracheostomy	ICU duration
Height (cm)	0.858	0.077	0.003	0.335	0.630	0.117	0.085
Weight (kg)	0.915	0.127	< 0.001	0.265	0.759	0.249	0.473
WC (mm)	0.801	0.209	< 0.001	0.103	0.701	0.183	0.437
C-index	0.374	0.499	0.025	0.102	0.635	0.134	0.020
ABSI	0.390	0.282	0.334	0.165	0.550	0.174	0.014
RFM	0.492	0.614	< 0.001	0.333	0.944	0.382	0.210
WHtR	0.743	0.509	< 0.001	0.202	0.839	0.433	0.145
BRI	0.895	0.462	< 0.001	0.154	0.730	0.473	0.122
BMI (kg/m ²)	0.979	0.341	< 0.001	0.421	0.972	0.914	0.907
AKI: acute kidney injury; CRRT: continuous renal replacement therapy; WC: waist circumference; C-index: conicity index; ABSI: a body shape index; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; BMI: body mass index.							

Scatter plot of P values from univariate analyses between anthropometric variables and outcomes.

Independent risk factors and cut-off threshold analysis of postoperative AKI

Given the associations between anthropometric variables and postoperative AKI, risk factor analyses were performed (Table 1). LASSO regression was applied to minimize multicollinearity among these anthropometric variables. Subsequently, a multivariable logistic regression identified seven factors that remained significantly associated with postoperative AKI: sex, RFM, neutrophil count, time from admission to operation, CPB duration, aortic clamping duration, and low body circulatory arrest duration. No significant multicollinearity existed among these independent risk factors (Table S10). AME was calculated to estimate the impact of RFM on the probability of postoperative AKI while holding other covariate variables at their mean levels. For the average patient, each one-unit increase in RFM was associated with a 2.10% (95% CI: 0.0131–0.0288, $P < 0.001$) change in the probability of postoperative AKI, 2.08% (95% CI: 0.0118–0.0299, $P < 0.001$) for male and 2.13% (95% CI: 0.0056–0.0371, $P = 0.0079$) for female (Table 2 and Fig. 2).

Table 1
Univariate and multivariable logistic regression analyses of postoperative AKI

Variables	Overall (n = 785)	AKI group (n = 302)	Non-AKI group (n = 483)	Univariate P value	OR	95% CI	Multivariate P value
Male (%)	609 (77.5)	254 (84.1)	354 (73.3)	0.001	1.688	1.078– 2.642	0.022
Age, year (SD)	50.65 (11.19)	49.77 (10.55)	51.18 (11.55)	0.087			
Height, cm (SD)	167.22 (7.62)	168.23 (7.61)	166.59 (7.57)	0.003	Excluded by LASSO regression		
Weight, kg (SD)	73.08 (14.13)	77.06 (14.38)	70.60 (13.40)	< 0.001			
WC, mm (SD)	913.0 (111.88)	944.16 (102.70)	895.41 (105.60)	< 0.001	Excluded by LASSO regression		
C-index (SD)	1.27 (0.09)	1.28 (0.07)	1.27 (0.08)	0.001	Excluded by LASSO regression		
ABSI (SD)	0.08 (0.01)	0.08 (0.00)	0.08 (0.01)	0.334			
RFM (SD)	38.95 (4.20)	40.00 (3.70)	38.33 (4.32)	< 0.001	1.098	1.052– 1.146	< 0.001
WHtR (SD)	0.55 (0.06)	0.56 (0.06)	0.54 (0.06)	< 0.001	Excluded by LASSO regression		
BRI (SD)	4.34 (1.28)	4.65 (1.22)	4.17 (1.25)	< 0.001	Excluded by LASSO regression		
BMI (SD)	26.02 (4.06)	27.10 (4.01)	25.35 (3.95)	< 0.001	Excluded by LASSO regression		
Hypertension (%)	576 (73.3)	234 (77.5)	341 (70.6)	0.042	Excluded by multivariate regression		
CAD (%)	41 (5.2)	15 (5.0)	26 (5.4)	0.928			
Previous heart surgery (%)	12 (1.5)	3 (1.0)	9 (1.9)	0.504			
Diabetes mellitus (%)	26 (3.3)	12 (4.0)	14 (2.9)	0.539			
Smoker (%)	314 (39.9)	142 (47.0)	171 (35.4)	0.002	Excluded by multivariate regression		

AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; LASSO: least absolute shrinkage and selection operator; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO₂: peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.

Variables	Overall (n = 785)	AKI group (n = 302)	Non-AKI group (n = 483)	Univariate P value	OR	95% CI	Multivariate P value
SpO2 at admission, % (SD)	95.78 (2.68)	95.72 (2.45)	95.82 (2.82)	0.600			
White blood cell count, 10 ⁹ /L (SD)	12.70 (3.76)	13.71 (3.56)	12.07 (3.74)	< 0.001	Excluded by LASSO regression		
Neutrophil count, 10 ⁹ /L (SD)	10.93 (3.61)	11.94 (3.41)	10.31 (3.59)	< 0.001	1.089	1.037– 1.144	< 0.001
Lymphocyte count, 10 ⁹ /L (SD)	1.02 (0.47)	0.99 (0.45)	1.04 (0.49)	0.199			
Hematocrit, % (SD)	39.33 (5.25)	40.71 (4.77)	38.48 (5.36)	< 0.001	1.037	0.999– 1.077	0.059
Platelet count, 10 ⁹ /L (SD)	182.00 (71.62)	178.69 (69.27)	183.76 (72.81)	0.334			
PT, s (SD)	13.85 (2.06)	13.76 (2.02)	13.91 (2.09)	0.317			
INR (SD)	1.10 (0.19)	1.10 (0.19)	1.10 (0.19)	0.790			
APTT, s (SD)	37.04 (7.22)	36.15 (6.88)	37.61 (7.38)	0.006	0.979	0.956– 1.003	0.086
Alanine transaminase, U/L (IQR)	21.80 [14.10, 35.20]	24.00 [15.25, 38.75]	20.50 [13.55, 33.35]	0.004	0.999	0.998– 1.000	0.107
Aspartate transaminase, U/L (IQR)	23.20 [17.90, 34.98]	24.85 [18.90, 36.77]	22.20 [17.00, 33.00]	0.002	Excluded by multivariate regression		
Total bilirubin, µmol/L (SD)	17.03 (13.49)	16.46 (7.85)	17.39 (16.06)	0.350			
Direct bilirubin, µmol/L (SD)	5.89 (3.59)	5.51 (2.74)	6.13 (4.02)	0.018	0.962	0.913– 1.013	0.143
Creatinine, µmol/L (SD)	122.78 (121.69)	115.66 (61.17)	127.20 (147.41)	0.197			
Left ventricle diameter, cm (SD)	46.86 (5.98)	46.45 (5.40)	47.11 (6.31)	0.138			
LVEF, % (SD)	65.08 (7.13)	64.90 (7.13)	65.18 (7.12)	0.598			

AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; LASSO: least absolute shrinkage and selection operator; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO₂: peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.

Variables	Overall (n = 785)	AKI group (n = 302)	Non-AKI group (n = 483)	Univariate P value	OR	95% CI	Multivariate P value
Time from onset to admission, h (SD)	13.00 [8.00, 24.00]	11.00 [8.00, 18.00]	15.00 [9.00, 36.00]	< 0.001	0.996	0.991–1.001	0.116
Time from admission to operation, h (SD)	16.00 [10.00, 28.45]	14.37 [9.67, 24.00]	17.00 [11.00, 32.16]	0.002	0.994	0.989–0.999	0.014
Surgeon (%)				0.010	0.822	0.626–1.079	0.157
1	264 (33.6)	82 (27.2)	182 (37.7)				
2	253 (32.2)	114 (37.7)	139 (28.8)				
3	252 (32.1)	98 (32.5)	153 (31.7)				
4	17 (2.2)	8 (2.6)	9 (1.9)				
Concomitant procedures (%)							
Bentall	53 (6.7)	18 (6.0)	35 (7.2)	0.581			
Aortic sinus repair	408 (51.9)	164 (54.3)	244 (50.5)	0.337			
CABG	47 (6.0)	21 (7.0)	26 (5.4)	0.455			
Cannulation (%)				0.079			
Axillary artery	447 (56.9)	159 (52.6)	288 (59.6)				
Femoral artery	119 (15.1)	45 (14.9)	74 (15.3)				
Axillary and femoral artery	203 (25.8)	88 (29.1)	114 (23.6)				
Others	17 (2.2)	10 (3.3)	7 (1.4)				
Times, min (SD)							
CPB	230.44 (94.26)	253.47 (100.61)	215.98 (87.21)	< 0.001	1.010	1.005–1.015	< 0.001
AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; LASSO: least absolute shrinkage and selection operator; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.							

Variables	Overall (n = 785)	AKI group (n = 302)	Non-AKI group (n = 483)	Univariate P value	OR	95% CI	Multivariate P value
Aorta clamping	108.87 (55.07)	118.51 (58.41)	102.88 (52.09)	< 0.001	0.990	0.983– 0.997	0.006
LBCA	21.22 (7.78)	22.58 (8.02)	20.35 (7.51)	< 0.001	1.028	1.002– 1.055	0.036
Re-CPB (%)	122 (15.5)	59 (19.5)	63 (13.0)	0.019	1.537	0.975– 2.537	0.064
LBCA flow, L/min (SD)	1.36 (0.64)	1.32 (0.65)	1.39 (0.63)	0.098			
Nasopharyngeal temperature, °C (SD)	27.76 (2.03)	27.49 (1.95)	27.92 (2.07)	0.004	Excluded by LASSO regression		
Bladder temperature, °C (SD)	28.58 (2.21)	28.31 (2.07)	28.75 (2.29)	0.007	Excluded by LASSO regression		
AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; LASSO: least absolute shrinkage and selection operator; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.							

Table S10
Multicollinearity analysis models of postoperative AKI

Variables	VIF	
	Independent Variables Model	Interaction Model
Sex	1.59	1.00
RFM	1.05	Excluded
Neutrophil count	1.07	1.01
Time from admission to operation	1.04	1.02
CPB duration	4.39	Excluded
Aorta clamping duration	4.84	3.60
LBCA duration	1.48	Excluded
RFM × CPB duration	Not included	3.62
VIF: variance inflation factor; RFM: relative fat mass; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.		

Table 2
Adjusted odds ratios and marginal effect of RFM on postoperative AKI

Subgroups	Multivariable analyses			Average marginal effect analyses		
	OR	95%CI	P value	Average marginal effect	95%CI	P value
Overall	1.098	1.052–1.146	< 0.001	2.10%	0.0131–0.0288	< 0.001
Male	1.103	1.054–1.155	< 0.001	2.08%	0.0118–0.0299	< 0.001
Female	1.127	1.024–1.240	0.0141	2.13%	0.0056–0.0371	0.0079
Models are adjusted for covariates including sex (not included in the subgroups analyses), neutrophil count, time from admission to operation, CPB duration, aorta clamping duration and low body circulatory arrest duration.						
AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; RFM: relative fat mass.						

Average marginal effect of relative fat mass (RFM) on postoperative acute kidney injury (AKI) in the overall cohort and stratified by sex. Error bars represent the 95% confidence intervals for the average marginal effects. (RFM: relative fat mass; AKI: acute kidney injury).

To further investigate the impact of RFM on AKI, an interaction term, “RFM × CPB duration,” was introduced into the analysis. Interestingly, in the interaction model, this term remained statistically significant, whereas the independent effects of RFM and CPB duration alone were no longer significant (Table 3). Furthermore, mediation analysis revealed that RFM exerts a significant average causal mediation effect on AKI through neutrophil count, with a mediated proportion of 12.5% (Table S11).

Table 3
Adjusted odds ratios of independent variables model and interaction model on postoperative AKI

Variables	Independent variables model			Interaction model		
	OR	95%CI	P value	OR	95%CI	P value
Sex	1.688	1.078–2.642	0.022	1.913	1.290–2.837	0.001
RFM	1.098	1.052–1.146	< 0.001	0.997	0.895–1.110	0.950
Neutrophil count	1.089	1.037–1.144	< 0.001	1.110	1.061–1.161	< 0.001
Time from admission to operation	0.994	0.989–0.999	0.014	0.994	0.989–0.999	0.012
CPB duration	1.010	1.005–1.015	< 0.001	0.992	0.976–1.008	0.310
Aorta clamping duration	0.990	0.983–0.997	0.006	0.991	0.985–0.997	0.005
LBCA duration	1.028	1.002–1.055	0.036	1.018	0.993–1.044	0.153
RFM × CPB duration	Not included			1.0004	1.0000-1.0009	0.040
AKI: acute kidney injury; OR: odds ratio; CI: confidence interval; RFM: relative fat mass; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.						

Table S11
Mediating role of neutrophil count in RFM and postoperative AKI

Effects	Estimate	95% CI	P value
Average Causal Mediation Effect	0.000117	(0.000000-0.000019)	< 0.000001
Average Direct Effect	0.000825	(0.000000-0.000226)	< 0.000001
Proportion mediated	0.1250	(0.0551-0.2400)	< 0.000001
RFM: relative fat mass; AKI: acute kidney injury; CI: confidence interval.			

Nonlinear association between anthropometric variables and short-term mortality

Independent risk factors for short-term mortality included platelet count (OR = 0.994; 95% CI: 0.989-1.000; P = 0.0042) aortic sinus repair (OR = 0.414; 95% CI: 0.218–0.787; P = 0.007), duration of CPB (OR = 1.006; 95% CI: 1.004–1.009; P < 0.001), and re-CPB (OR = 3.092; 95% CI: 1.600-5.973; P < 0.001). No significant multicollinearity existed among these four variables (Table S1). Using RCS models with three knots, WC, RFM, WHtR, and BRI each showed a nonlinear association (U-shaped) with short-term mortality. The cut-off thresholds corresponding to the lowest predicted probability of short-term mortality were 907 mm for WC, 38.5 for RFM, 0.544 for WHtR, and 4.35 for BRI, respectively (Fig. 3). However, no significant nonlinear association was found in subgroup analyses stratified by sex revealed (Table S12).

- U-shaped association between anthropometric variables and probability of short-term mortality: (A) WC, (B) RFM, (C) WHtR, and (D) BRI. (WC: waist circumference, RFM: relative fat mass, WHtR: waist-to-height ratio, and BRI: body roundness index).

Table S12
Restricted cubic spline analysis

Variables	Coef	Standard Error	Wald Z	P value
WC linear	-0.005	0.003	-1.69	0.092
WC nonlinear	0.008	0.003	2.23	0.026
Age	-0.004	0.016	-0.23	0.821
Male	-0.659	0.377	-1.75	0.081
Platelet count	-0.006	0.003	-2.01	0.045
Aortic sinus repair	-0.794	0.335	-2.37	0.018
CPB duartion	0.006	0.001	4.58	< 0.001
Re-CPB	1.213	0.344	3.52	< 0.001
Previous heart surgery	0.902	0.878	1.03	0.304
Intercept	1.327	2.585	0.51	0.608
RFM linear	-0.113	0.061	-1.87	0.062
RFM nonlinear	0.158	0.075	2.10	0.036
Age	-0.004	0.016	-0.23	0.819
Male	-0.638	0.365	-1.75	0.081
Platelet count	-0.006	0.003	-2.06	0.039
Aortic sinus repair	-0.808	0.336	-2.41	0.016
CPB duartion	0.006	0.001	4.51	< 0.001
Re-CPB	1.166	0.344	3.39	0.001
Previous heart surgery	0.853	0.874	0.98	0.329
Intercept	1.303	2.310	0.56	0.573
RFM linear in male	-0.1323	0.0720	-1.84	0.0663
RFM nonlinear in male	0.1684	0.0947	1.78	0.0753
Age	0.0050	0.0183	0.27	0.7858
Platelet count	-0.0057	0.0035	-1.62	0.1058
Aortic sinus repair	-0.7218	0.3930	-1.84	0.0663
CPB duartion	0.0049	0.0015	3.31	0.0009
Re-CPB	1.0467	0.4017	2.61	0.0092
Previous heart surgery	0.6977	1.1083	0.63	0.5290
WC: waist circumference; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; CPB: cardiopulmonary bypass.				

Variables	Coef	Standard Error	Wald Z	P value
Intercept	1.2409	2.6992	0.46	0.6457
RFM linear in female	-0.0677	0.1143	-0.59	0.5539
RFM nonlinear in female	0.1247	0.1181	1.06	0.2909
Age	-0.0297	0.0315	-0.94	0.3455
Platelet count	-0.0111	0.0071	-1.56	0.1177
Aortic sinus repair	-1.0031	0.6462	-1.55	0.1206
CPB duartion	0.0125	0.0036	3.45	0.0006
Re-CPB	1.8757	0.7489	2.50	0.0123
Previous heart surgery	0.7529	2.1123	0.36	0.7215
Intercept	0.0452	4.5752	0.01	0.9921
WHtR linear	-8.9041	4.9466	-1.8	0.072
WHtR nonlinear	12.4568	5.8135	2.14	0.032
Age	-0.004	0.0156	-0.26	0.796
Male	-0.6425	0.3654	-1.76	0.079
Platelet count	-0.0063	0.003	-2.07	0.038
Aortic sinus repair	-0.8005	0.3357	-2.38	0.017
CPB duartion	0.0062	0.0014	4.52	< 0.001
Re-CPB	1.1704	0.3437	3.41	0.001
Previous heart surgery	0.8208	0.8698	0.94	0.345
Intercept	1.7955	2.632	0.68	0.495
BRI linear	-0.447	0.260	-1.72	0.085
BRI nonlinear	0.637	0.303	2.10	0.035
Age	-0.004	0.016	-2.38	0.780
Male	-0.645	0.366	-1.76	0.078
Platelet count	-0.006	0.003	-2.02	0.037
Aortic sinus repair	-0.798	0.336	-2.38	0.018
CPB duartion	0.006	0.001	4.53	< 0.001
Re-CPB	1.174	0.344	3.41	0.001
Previous heart surgery	0.806	0.869	0.93	0.354
WC: waist circumference; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; CPB: cardiopulmonary bypass.				

Variables	Coef	Standard Error	Wald Z	P value
Intercept	-1.093	1.445	-0.76	0.450
WC: waist circumference; RFM: relative fat mass; WHtR: waist-to-height ratio; BRI: body roundness index; CPB: cardiopulmonary bypass.				

Considering the association of RFM with postoperative AKI and short-term mortality, the cohort was stratified into three groups (thresholds: 38 and 39) to simulate a U-shaped relationship, with the middle group (RFM: 38–39) representing the lowest mortality risk. Although differences were not statistically significant, the middle group exhibited the lowest short-term mortality and shortest CPB duration among the three groups (Table S13).

Table S13
Overall and Pairwise Comparisons Among RFM Groups

Variables	Low RFM group (RFM < 38, n = 425)	Middle RFM group (RFM: 38–39, n = 91)	High RFM group (RFM ≥ 39, n = 278)	P value			
				Overall	Mid-Low	High-Low	High-Mid
Male (%)	323 (76.0)	71 (78.0)	218 (78.4)	0.752			
Age, year (SD)	49.92 (11.06)	51.99 (10.02)	51.32 (11.73)	0.130			
Height, cm (SD)	166.60 (7.26)	167.58 (8.24)	167.92 (8.14)	0.076			
Weight, kg (SD)	79.30 (13.79)	71.03 (10.36)	63.93 (10.27)	< 0.001	< 0.001	< 0.001	< 0.001
WC, mm (SD)	984.70 (81.27)	893.74 (43.81)	810.66 (62.64)	< 0.001	< 0.001	< 0.001	< 0.001
C-index (SD)	1.32 (0.06)	1.27 (0.05)	1.21 (0.06)	< 0.001	< 0.001	< 0.001	< 0.001
ABSI (SD)	0.08 (0.00)	0.08 (0.00)	0.08 (0.00)	< 0.001	< 0.001	< 0.001	< 0.001
WHtR (SD)	0.59 (0.04)	0.53 (0.00)	0.48 (0.03)	< 0.001	< 0.001	< 0.001	< 0.001
BRI (SD)	5.26 (0.93)	4.01 (0.08)	3.06 (0.55)	< 0.001	< 0.001	< 0.001	< 0.001
BMI (SD)	28.41 (3.51)	25.15 (2.01)	22.58 (2.55)	< 0.001	< 0.001	< 0.001	< 0.001
Hypertension (%)	335 (78.8)	63 (69.2)	184 (66.2)	< 0.001	1.000	< 0.001	0.163
CAD (%)	26 (6.1)	5 (5.5)	11 (4.0)	0.455			
Previous heart surgery (%)	6 (1.4)	1 (1.1)	7 (2.5)	0.625			
Diabetes mellitus (%)	21 (4.9)	2 (2.2)	4 (1.4)	0.035	1.000	0.060	1.000
Smoker (%)	161 (37.9)	39 (42.9)	115 (41.4)	0.525			
SpO2 at admission, % (SD)	95.41 (2.85)	95.56 (2.72)	96.38 (2.38)	< 0.001	0.030	< 0.001	0.873

OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO₂: peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.

Variables	Low RFM group (RFM < 38, n = 425)	Middle RFM group (RFM: 38–39, n = 91)	High RFM group (RFM ≥ 39, n = 278)	P value			
				Overall	Mid-Low	High-Low	High-Mid
White blood cell count, 10 ⁹ /L (SD)	13.34 (3.46)	12.60 (4.02)	11.80 (3.93)	< 0.001	0.172	< 0.001	0.201
Neutrophil count, 10 ⁹ /L (SD)	11.51 (3.36)	10.93 (3.87)	10.10 (3.74)	< 0.001	0.131	< 0.001	0.329
Lymphocyte count, 10 ⁹ /L (SD)	1.08 (0.49)	0.94 (0.39)	0.95 (0.47)	< 0.001	0.975	< 0.001	0.022
Hematocrit, % (SD)	40.28 (5.05)	39.17 (4.81)	37.94 (5.47)	< 0.001	0.120	< 0.001	0.156
Platelet count, 10 ⁹ /L (SD)	184.87 (71.07)	173.20 (68.63)	178.69 (72.20)	0.271			
PT, s (SD)	13.69 (1.83)	14.23 (2.36)	14.04 (2.36)	0.022	0.738	0.075	0.066
INR (SD)	1.08 (0.16)	1.13 (0.22)	1.12 (0.23)	0.013	0.953	0.026	0.103
APTT, s (SD)	36.49 (7.05)	37.95 (6.92)	37.63 (7.50)	0.055			
Alanine transaminase, U/L (IQR)	24.60 [16.80, 40.10]	21.80 [14.80, 32.80]	16.70 [11.93, 28.00]	< 0.001	0.036	< 0.001	0.058
Aspartate transaminase, U/L (IQR)	23.30 [18.00, 36.00]	23.40 [18.25, 35.20]	22.55 [16.90, 33.72]	0.402			
Total bilirubin, μmol/L (SD)	17.57 (16.32)	16.55 (8.95)	16.49 (9.14)	0.539			
Direct bilirubin, μmol/L (SD)	5.95 (3.58)	5.99 (3.85)	5.82 (3.54)	0.874			
Creatinine, μmol/L (SD)	115.97 (83.07)	120.78 (99.92)	132.74 (167.47)	0.198			
Left ventricle diameter, cm (SD)	46.52 (5.56)	46.68 (6.08)	47.35 (6.59)	0.168			
LVEF, % (SD)	64.61 (7.20)	65.95 (5.82)	65.37 (7.43)	0.194			
OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.							

Variables	Low RFM group (RFM < 38, n = 425)	Middle RFM group (RFM: 38–39, n = 91)	High RFM group (RFM ≥ 39, n = 278)	P value			
				Overall	Mid-Low	High-Low	High-Mid
Time from onset to admission, h (SD)	12.00 [8.00, 23.00]	12.00 [8.00, 28.50]	15.00 [10.00, 27.00]	0.004	0.248	0.0015	0.684
Time from admission to operation, h (SD)	16.00 [9.83, 27.00]	15.00 [9.84, 27.12]	16.50 [10.50, 31.00]	0.339			
Surgeon (%)				0.261			
1	142 (33.4)	31 (34.1)	93 (33.5)				
2	145 (34.1)	32 (35.2)	77 (27.7)				
3	128 (30.1)	25 (27.5)	104 (37.4)				
4	10 (2.4)	3 (3.3)	4 (1.4)				
Concomitant procedures (%)							
Bentall	19 (4.5)	5 (5.5)	29 (10.4)	0.007			
Aortic sinus repair	226 (53.2)	58 (63.7)	125 (45.0)	0.005			
CABG	23 (5.4)	7 (7.7)	19 (6.8)	0.607			
Cannulation (%)				0.302			
Axillary artery	232 (54.6)	54 (59.3)	164 (59.0)				
Femoral artery	64 (15.1)	13 (14.3)	45 (16.2)				
Axillary and femoral artery	123 (28.9)	21 (23.1)	61 (21.9)				
Others	6 (1.4)	3 (3.3)	8 (2.9)				
Times, min (SD)							
CPB	233.07 (97.27)	227.62 (85.79)	232.97 (100.69)	0.883			
OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.							

Variables	Low RFM group (RFM < 38, n = 425)	Middle RFM group (RFM: 38–39, n = 91)	High RFM group (RFM ≥ 39, n = 278)	P value			
				Overall	Mid-Low	High-Low	High-Mid
Aorta clamping	109.78 (56.62)	106.49 (49.80)	109.91 (55.19)	0.863			
LBCA	21.65 (7.99)	21.35 (7.14)	20.50 (7.94)	0.162			
Re-CPB (%)	70 (16.5)	11 (12.1)	46 (16.5)	0.558			
LBCA flow, L/min (SD)	1.37 (0.62)	1.30 (0.72)	1.37 (0.64)	0.601			
Nasopharyngeal temperature, °C (SD)	27.75 (2.01)	27.80 (1.99)	27.70 (2.11)	0.910			
Bladder temperature, °C (SD)	28.62 (2.22)	28.59 (2.18)	28.45 (2.25)	0.588			
Short-term mortality (%)	28 (6.6)	2 (2.2)	19 (6.8)	0.244			
OR: odds ratio; CI: confidence interval; SD: standard deviation; IQR: interquartile range; WC: waist circumference; C-index: conicity index; ABSI: A body shape index; RFM: relative fat mass; BRI: body roundness index; WHtR: waist-to-height ratio; BMI: body mass index; CAD: coronary artery disease; SpO ₂ : peripheral oxygen saturation; PT: prothrombin time; INR: international normalized ratio; APTT: activated partial thromboplastin time; LVEF: left ventricular ejection fraction; CABG: coronary artery bypass grafting; CPB: cardiopulmonary bypass; LBCA: lower body circulatory arrest.							

Discussion

The impact of obesity on surgical outcomes of ATAAD have been debated as the “obesity paradox” still remains controversial. Besides the classical index of body measurement—BMI, the impact of other novel anthropometric variables on short-term outcomes in ATAAD has not been reported. The key findings of the present study were as follows: (1) RFM was found independently associated with postoperative AKI and in ATAAD, partially mediated by neutrophil count, and RFM and CPB duration had a synergistic effect on postoperative AKI; (2) WC, RFM, WHtR, and BRI showed nonlinear associations with short-term mortality in ATAAD, presenting a U-shaped relationship; (3) the cut-off thresholds for anthropometric variables associated with postoperative AKI and short-term mortality were also identified.

RFM and postoperative AKI

AKI frequently occurs after ATAAD repair, with reported incidence rates ranging from 23% to 51% [18, 19]. Unfortunately, beyond renal replacement therapy, effective targeting therapies to prevent or cure AKI remain limited [20]. Therefore, early identification of risk factors for postoperative AKI in patients undergoing ATAAD repair is critical to improve clinical outcomes.

Elevated BMI was a recognized risk factor for AKI following both ATAAD repair [18, 21] and noncardiac surgeries [22]. However, in the present study, after addressing collinearity among variables, RFM emerged as a stronger predictor than BMI, suggesting that RFM may provide more independent and clinically valuable information for assessing AKI risk. BMI has limitations in differentiating between adipose and lean tissue [23]. In contrast, RFM is recognized as an effective indicator for both general and central obesity and has demonstrated utility in evaluating cardiovascular risk among Chinese populations [24].

Obesity predisposes patients to AKI through multiple interrelated mechanisms, including renal hemodynamics and intravascular volume assessment challenges [25], increased metabolic load on the glomeruli [26], excess abdominal pressure, comorbidities (e.g., hypertension, diabetes) [18], and heightened inflammatory and oxidative stress [27]. In this study, neutrophil count, a marker of acute inflammation/stress responses, partially mediated the relationship between RFM and postoperative AKI. Moreover, a significant synergistic interaction between RFM and CPB duration was observed, indicating that patients with both high RFM and prolonged CPB duration are at even greater risk for AKI. These findings suggest that the acute inflammatory/stress responses induced by the sudden onset of aortic dissection may be amplified in patients with elevated RFM, especially in those experiencing extended CPB. Furthermore, assessing intravascular volume status and managing fluid resuscitation in obese patients is inherently challenging. Consequently, the present study emphasizes the importance of RFM to stratify risk among ATAAD patients, especially among those undergoing prolonged CPB.

Anthropometric variables and short-term mortality

Obesity has been linked to many cardiovascular diseases, yet its impact on short-term mortality after ATAAD repair remains debated. A meta-analysis of 12 studies involving 5,522 patients found that perioperative mortality of ATAAD increased by 22% for each 1 kg/m² increase in BMI [28]. Consistent with the “obesity paradox” and our results, Feldeisen and colleagues demonstrated that maintaining a healthy weight did not necessarily lead to better surgical outcomes [4]. In the present study, BMI was not linearly associated with short-term mortality. However, a nonlinear relationship (U-shaped) was observed between short-term mortality and four anthropometric variables (WC, RFM, WHtR, and BRI). Notably, the cut-off thresholds for the lowest predicted probability of short-term mortality exceeded their normal ranges [7, 9, 10]. Moreover, these variables are considered superior to BMI for evaluating trunk fat or visceral fat [9, 10, 29, 30], and the “obesity paradox” was similarly identified in East Asian patients using composition of the abdominal fat area [31]. Therefore, we speculate that central obesity, which is more strongly associated with cardiometabolic risk factors than general obesity [32], may play a more important role in the surgical outcomes of ATAAD. Notably, shorter CPB duration might have contributed to the U-shaped relationship between RFM and short-term mortality, but this contribution may be restricted by the sample size of this study. Overall, further research is required to determine the role of central obesity and CPB duration on obesity paradox in ATAAD.

Strengths and limitations

To the best of our knowledge, this is the first study to investigate the associations between novel anthropometric variables and short-term outcomes in ATAAD. However, this study has several limitations. Because of its retrospective and observational design, the ability to establish a definitive causal relationship is limited and other classical markers of inflammation (e.g., C-reactive protein, procalcitonin) are missing. Moreover, the underlying mechanisms of the nonlinear relationship remain inadequately explained, and further research with a larger sample size is required in the future.

Conclusions

RFM emerged as an independent risk factor for postoperative AKI, with its impact partially mediated by the acute inflammatory/stress response and further synergize with prolonged CPB duration. Nonlinear (U-shaped) associations were observed between central obesity indicators (WC, RFM, WHtR, and BRI) and short-term mortality. RFM should be prioritized for optimizing perioperative management and risk stratification in ATAAD patients, especially in those undergoing extended CPB procedures.

Declarations

Disclosures and Acknowledgement:

None

Ethical approval and consent to participate

This retrospective study was approved by the ethics committee of the Second Xiangya Hospital of Central South University (LYF2023113) on August 2, 2023, and need for written informed consent was waived.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

Ling Tan: conceptualization, funding acquisition, supervision, project administration, resources, writing – review & editing; Chao Deng. and Wen Yao Zhan: conceptualization, data curation, formal analysis, investigation, methodology, software, validation, visualization, writing – original draft; Hao Tang: funding acquisition, supervision, project administration, resources; Kangjun Shen: writing – review & editing; Jingyu Li, Zhenxiong Li, and Song Tian: data curation and validation.

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None.

Data Availability

The original data in this article are not publicly available due to privacy concerns and ethical restrictions. However, the data can be obtained from the corresponding author upon reasonable request.

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Figures

Univariate analysis between anthropometric variables and outcomes

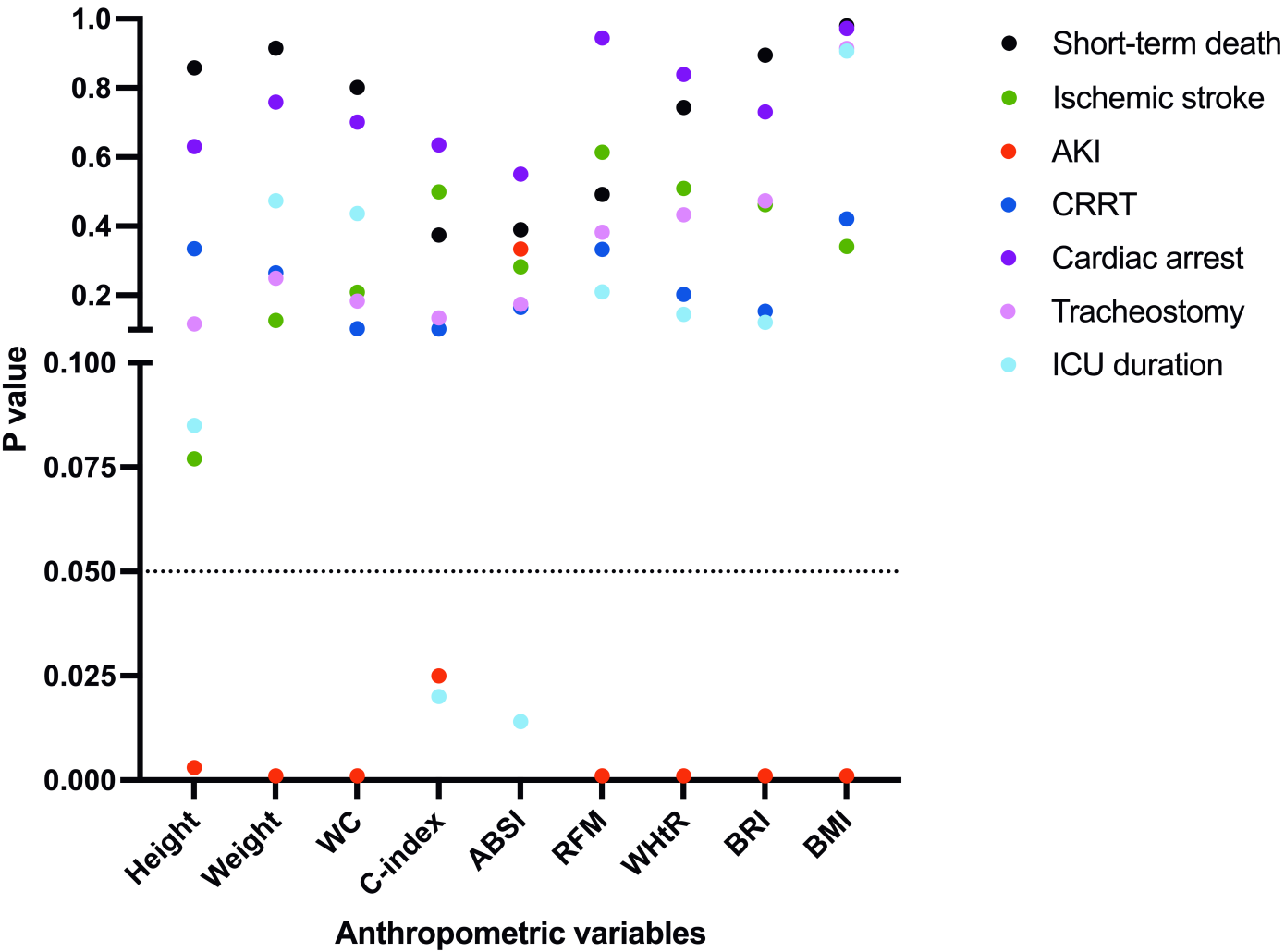


Figure 1

Average marginal effect of RFM on postoperative AKI

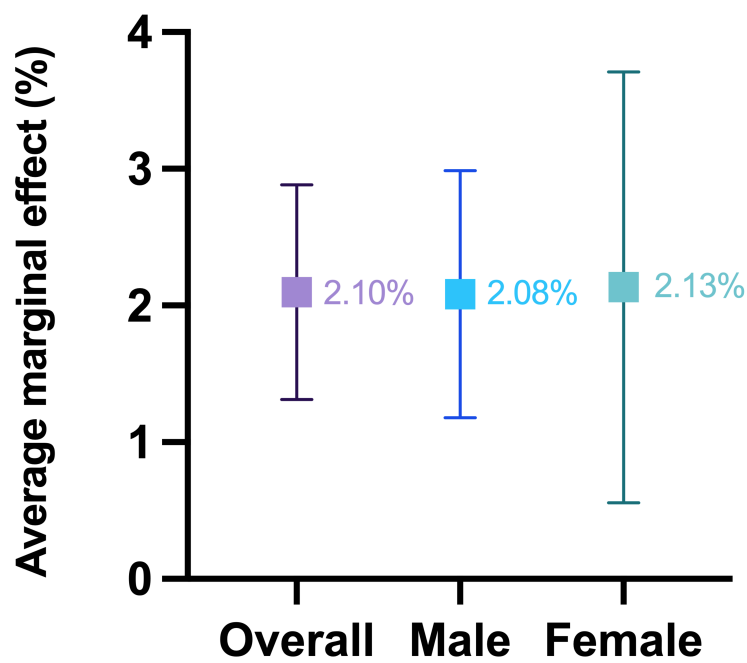


Figure 2

Average marginal effect of relative fat mass (RFM) on postoperative acute kidney injury (AKI) in the overall cohort and stratified by sex. Error bars represent the 95% confidence intervals for the average marginal effects. (RFM: relative fat mass; AKI: acute kidney injury).

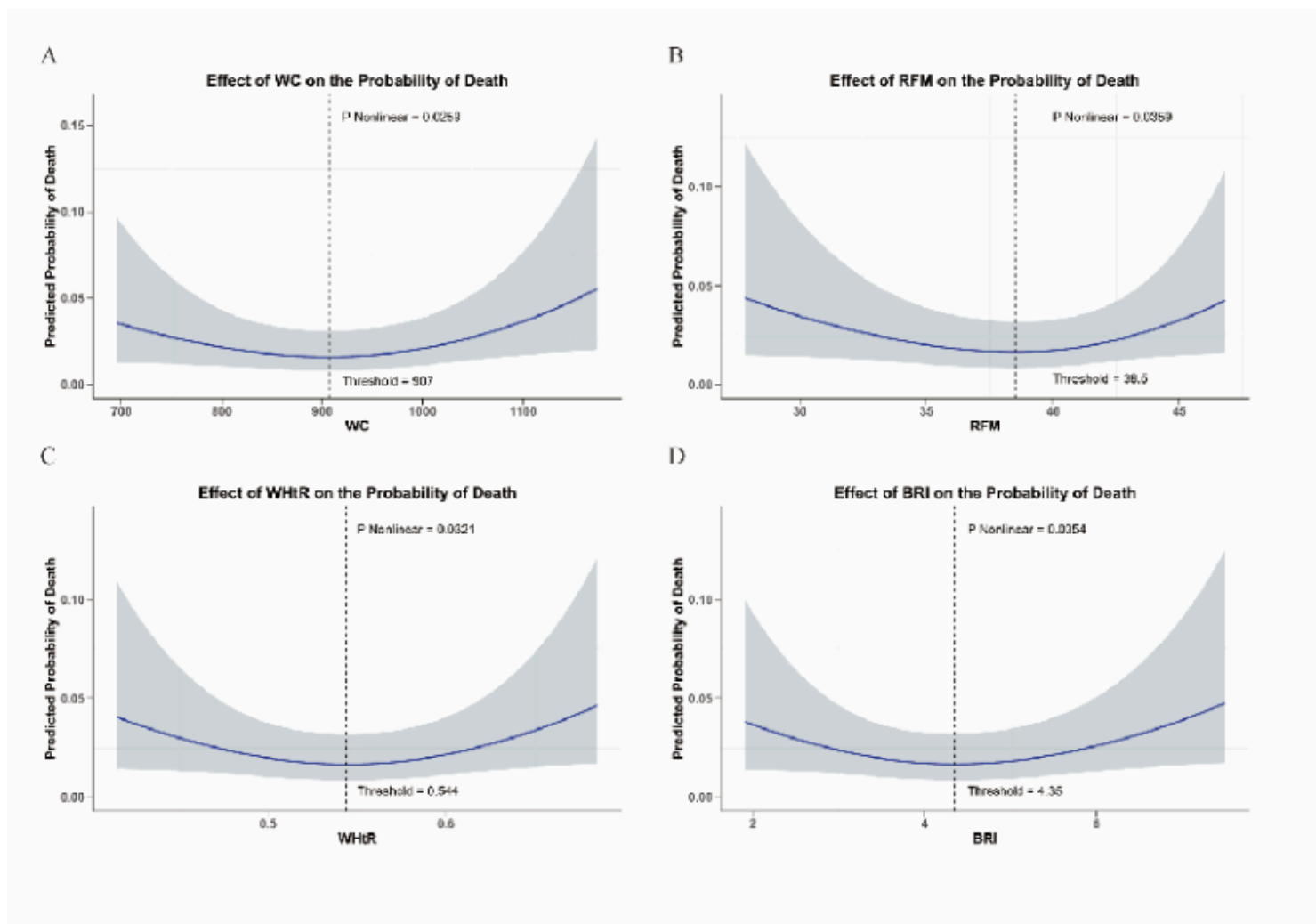


Figure 3

U-shaped association between anthropometric variables and probability of short-term mortality: (A) WC, (B) RFM, (C) WHtR, and (D) BRI. (WC: waist circumference, RFM: relative fat mass, WHtR: waist-to-height ratio, and BRI: body roundness index).